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Dynamic responses of railway ballasted track considering rail pad deterioration

Chayut Ngamkhanong^{1,2}, Keiichi Goto^{2,3} and Sakdirat Kaewunruen^{1,2}

¹Department of Civil Engineering, School of Engineering, University of Birmingham, Birmingham B152TT, United Kingdom

²Birmingham Centre for Railway Research and Education, School of Engineering, University of Birmingham, Birmingham B152TT, United Kingdom

³Railway Dynamics Division, Railway Technical Research Institute, Japan

cxn649@student.bham.ac.uk

Abstract. Rail pads, which can be made of polymeric compound, rubber, composite materials etc., are resilient components installed on rail seats between the rail and sleeper in order to attenuate the impact loads and moderate track stiffness at the special locations. Based on literature, rail pad can be deteriorated over time. This can change the dynamic characteristics of rail pads: stiffness and damping. This paper presents the dynamic responses of railway track with new rail pads and aged rail pads. It should be noted that the parameters used of rail pads were analysed using impact excitation technique and then adapted for this study. To study the dynamic responses, D-track software is used based on Winkler foundation principle. Wheel flat is considered as imperfect wheel for impact case. The results obtained show that rail pads deteriorations seem to have significant effects on the increasing of rail/sleeper contact force rather than wheel/rail contact force. It is known that softer pads normally have a better performance on reducing dynamic responses. Although, the stiffness of rail pads reduce over time, damping coefficient also decrease. These lead to a poor performance of rail pad resulting in the reducing of rail/sleeper contact force.

1. Introduction

Rail pads are resilient elastic pads installed on rail seats between the rail and sleeper. It is noticeable that rail pads, which can be commonly made of polymeric compound, rubber, composite materials etc., are the important component of railway track. The main duties of rail pads are to adjust the track stiffness at the differential track stiffness locations such as bridge transitions [1-2], switches and crossings [3] etc. It should be noted that these areas are prone to dynamic loading. This is used to reduce the differential track stiffness. In the stiffer portion of transition zone or bridge end, rail pads were used to reduce track stiffness [4].

In fact, railway track often experience high intensity impact load due to the irregularities of wheel or rail [5-6]. This is a high shock load applied in short duration with the frequency range between 0Hz and 2000Hz depending on vehicle velocities, types of wheel or rail defects etc [5]. While, the impact capacity of track components can be reduced due to material degradations and long term behaviour [7-13]. Another main duty of rail pads is attenuate the dynamic responses induced by wheel impacts [14].

The use of softer pad provided a better damping effects resulting in the reductions of forces acting and dynamic responses. As shown in previous study, the use of stiffer rail pad can induce cracking in concrete sleepers as the stress on sleeper was increased. It was clearly seen that the replacement of

stiffer pads by softer pads indicated a reduction of sleeper loads resulting in better ride comfort [1]. Thus, it should be noted that the performance of rail pads depends on the properties of rail pads used in those particular areas. Hence, it is important to consider the pad stiffness when selecting and applying pads [15].

According to previous studies, it is evident that deterioration rate has significant influence on the dynamic rail pad properties that affect the dynamic responses of railway tracks [16-17]. The experimental techniques using instrumented hammer coupled with modal analysis have been developed in order to extract the dynamic characteristics of rail pad [18-19]. In this study, it should be noted that the material properties of aged rail pad have been collected and extracted from previous studies at different years in service [20-22].

This paper presents the dynamic responses at the contact between rail and sleeper with rail pads. The study case of worn wheel flat was considered as an impact case to compare with the perfect wheel/rail contact. The material degradations of rail pads were taken into account based on previous experiments. The dynamic amplification factors are highlighted. The outcome of this study will help railway engineer in improving the predictive maintenance and inspection regimes.

2. Methodology

2.1. Simulation scenarios

D-Track software was used to simulate the static and dynamic responses of railway track based on Winkler foundation principal which cross section of track dynamic responses was considered symmetrically. It should be noted that Timoshenko beams were used to model the rails and sleepers as this take into account shear characteristics which have a significant effects on results [23]. The Timoshenko coefficients used for rails and sleepers were 0.833 and 0.34, respectively [24]. The numerical simulations were carried out using 106t freight wagon with wheel radius of 0.46m and Hertzian spring constant of $0.87 \times 10^{11} \text{ N/m}^{3/2}$.

Simulation scenarios and vehicle/track types are presented in table 1. It should be noted that worn wheel flat is considered as wheel/rail contact irregularity case. This causes high frequency impact force on railway track. It is noted that wheel flat is the most common local surface defect of wheels [5, 25-27].

Table 1. Simulation scenarios

Vehicle type	Track type	Train speed	Wheel/rail contact condition
106t Coal Wagon	Standard Gauge 1435mm 60kg/m rail, Prestressed concrete sleepers	20-100	No irregularity Worn wheel flat (Length = 75 mm, Depth = 1 mm)

2.2. Rail pad properties

An alternative rail pad tester based on the SDOF vibration response measurement for determining the dynamic properties of rail pads has been devised, as well as the state-dependent model of rail pads [19]. Total pad stiffness including both frequency-dependent stiffness and frequency-independent stiffness has been calculated based on modal testing with the consideration of state dependent model. HDPE (High Density Polyethylene) pads were used. The new rail pad and worn rail pads in the years in services of 18 and 20 were taken into account [19]. The damping coefficient and stiffness of rail pad are shown in figure 1. It was assumed that the deterioration rate was linear. The degradation equation of both damping and stiffness are noted in the Figure.

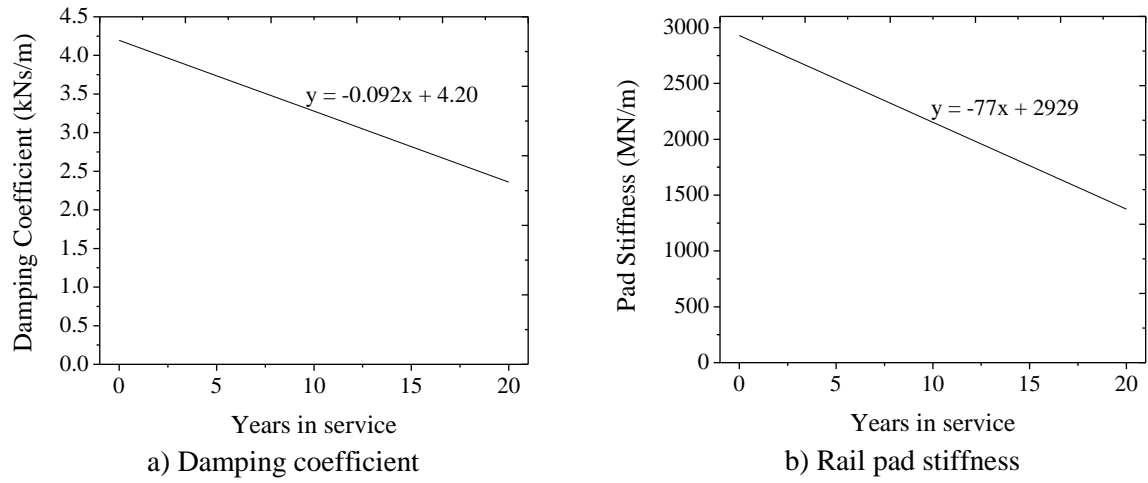


Figure 1. Dynamic properties of rail pad.

3. Results and Discussions

Figures 2-3 show the time histories of wheel/rail and rail/sleeper contact forces subjected to the train speed of 100 km/h. It should be noted that the analysis positions were at rail seat. The pulse durations were about 0.7 s. It can be seen from both figures that wheel flat defect play a role on the increasing of dynamic force. It is observed that railway track with new and aged rail pads have the same magnitude of wheel/rail contact forces. However, aged rail pads have significant effects on the rail/sleeper contact force in comparison with new rail pads, as seen in figure 3.

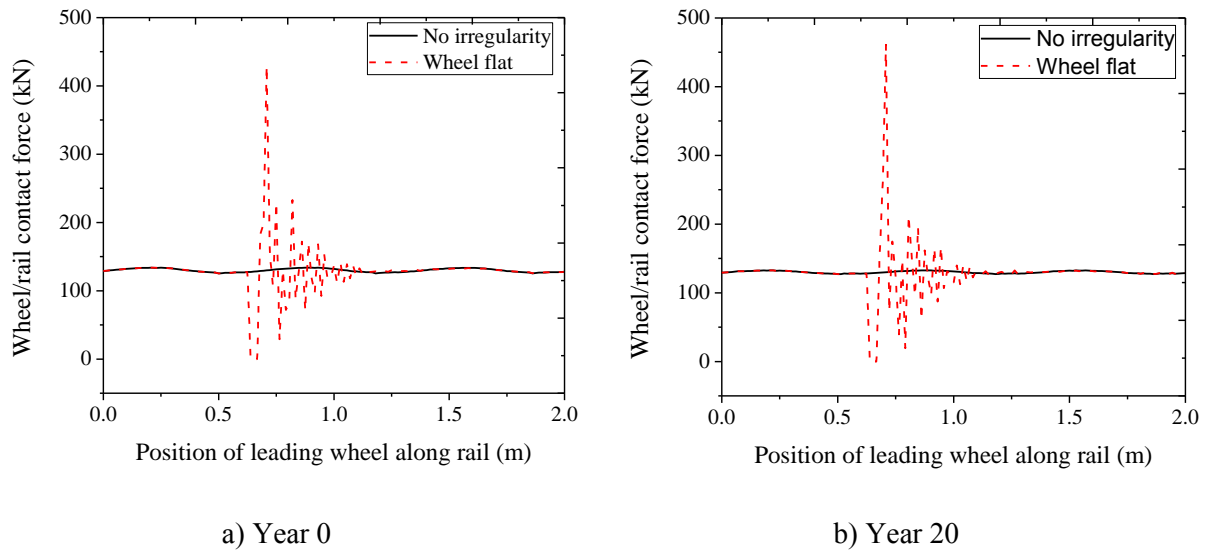
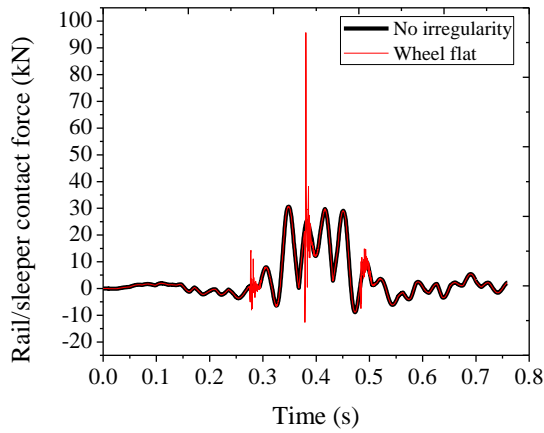
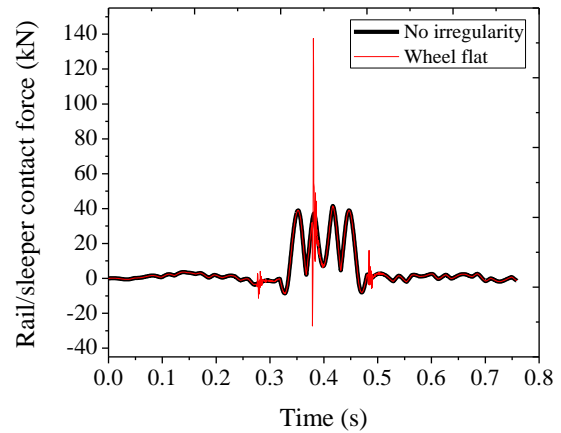


Figure 2. Wheel/rail contact force.



a) Year 0

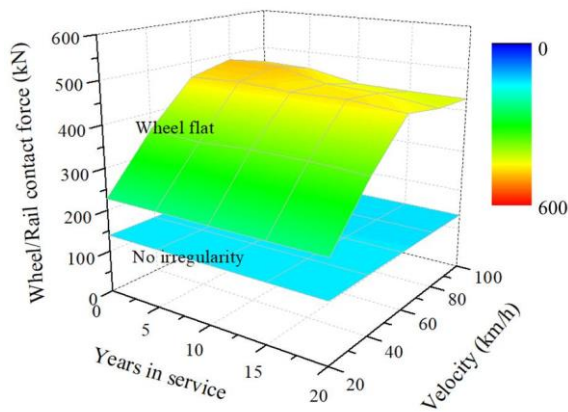


b) Year 20

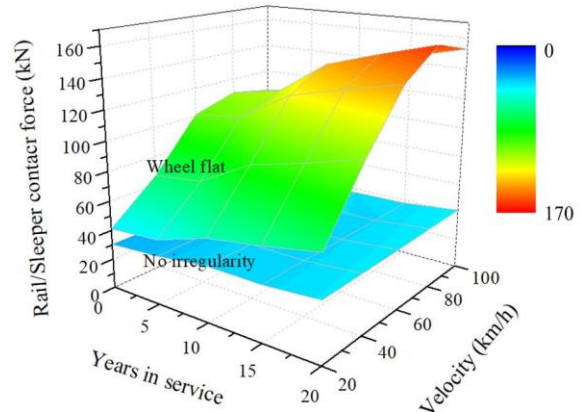
Figure 3. Rail/sleeper contact force at rail seat.

Wheel/rail contact force at different train velocities and years in service of rail pads are presented in figure 4a. It should be noted that for the perfect wheel/rail interaction, wheel/rail contact forces are about 140 kN. As for worn wheel flat case, contact forces increase nonlinearly with the increase of vehicle velocity. It is noted that rail pad deterioration does not play a role on wheel/rail contact force. It should be noted that wheel flats would create the forces varying from 0 to 2000 Hz, depending on the train speeds [5].

Figure 4b presents the rail/sleeper contact forces considering worn wheel flat. As for static case (no irregularity), the contact forces slightly linearly increase with the increasing of velocity and years in service. However, the increases are less than 5%. In case of worn wheel flat, the contact forces significantly increase with the increasing of train velocity. It is also noted that aged rail pad play a role in rail/sleeper contact force reduction especially at the higher speed.



a) Wheel/rail



b) Rail/sleeper

Figure 4. Contact force contour at different velocities over time.

The dynamic factor can be evaluated from rail/sleeper dynamic over static forces ratio, as illustrated in figure 5. Dynamic factors are in the range between 1.3 and 3.6 at year 0 and between 1.7 and 3.9 at year 20. Interestingly, rail pad degradations does not seem to play a role on wheel/rail

contact force as they show quite the same dynamic factor at different ages of rail pads. Nevertheless, they instead play a significant role on rail/sleeper contact force.

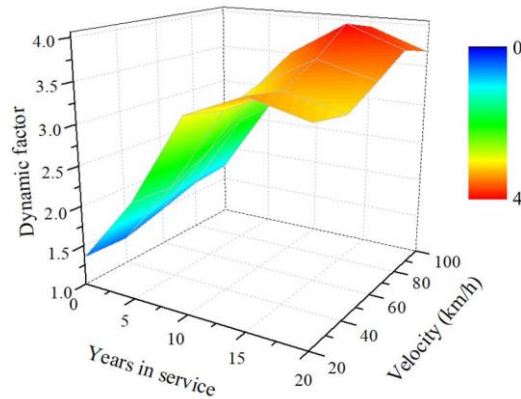


Figure 5. Dynamic factor.

4. Conclusions

This paper presents the dynamic response between vehicle and track considering degradations of rail pads. It is well known that rail pads are generally used in railway track in order to attenuate the dynamic load and adapt the overall track stiffness. The new and aged HDPE pads have been previously studied in terms of properties and then used in this study. It was noted that the dynamic stiffness and damping coefficient tended to reduce over the time. The results show that rail pads deteriorations seem to have significant effects on the increasing of rail/sleeper contact force rather than wheel/rail contact force. The increases of dynamic factor of rail/sleeper force of about 25% are noted. Although, the softer rail pads can significantly make benefit to railway track as seen in previous studies, damping properties, which are observed over time, reduce the damping performance which induce the higher rail/sleeper contact force.

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